AFRL-OSR-VA-TR-2015-0178

Toward Overcoming the Local Minimum Trap in MFBD

James Nagy
EMORY UNIVERSITY

07/14/2015
Final Report

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
14-06-2015	Final Performance Report	15/3/2012 - 14/3/2015

4. TITLE AND SUBTITLE
Toward Overcoming the Local Minimum Trap in MFBD

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-12-1-0084

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James G. Nagy

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Emory University
400 Dowman Drive
Atlanta, GA 30322-1018;

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USAF, AFRL, AF Office of Scientific Research
875 N. Randolph St., Room 3112
Arlington, VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems.
In the three years of this grant, we have developed software, investigated the use of implicit filtering methods to avoid local minima, considered Gaussian Markov random fields to improve regularization, and we have developed methods for sparsity constraints that can be used for large scale MFBD problems. The work done on this, and a previous AFOSR grant, initiated a very productive collaboration with Dr. Stuart Jefferies, IFA,

15. SUBJECT TERMS
Multi-frame blind deconvolution, optimization, local minimum, regularization, filtering

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*

Reset

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

AFOSR Final Project Report

Proposal Title:	**Toward Overcoming the Local Minimum Trap in MFBD**
Proposal Number:	**FA9550-12-1-0084**
PI:	**James Nagy** **Professor** **Mathematics and Computer Science** **Emory University** **Atlanta, GA**
Program Manager:	**Dr. Julie Moses**

Project Summary

Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems.

In the three years of this grant, we have developed software, investigated the use of implicit filtering methods to avoid local minima, considered Gaussian Markov random fields to improve regularization, and we have developed methods for sparsity constraints that can be used for large scale MFBD problems. The work done on this, and a previous AFOSR grant, initiated a very productive collaboration with Dr. Stuart Jefferies, IFA, University of Hawaii, Dr. Douglas Hope, U.S. Air Force Academy, and Dr. Michael Hart, Physics and Astronomy, University of Arizona.

Accomplishments for Period: March 15, 2012 – March 14, 2015

Graduate Student Support. This grant was used to partially support three graduate students:

Student	# years in PhD program	Months of support
Qing Chu	5	8
Sebastian Berisha	5	6.75
Keith Kelly	2	6
Clarissa Garvey	2	6

Qing Chu completed her PhD in summer 2013, and Sebastian Berisha completed his PhD in summer 2014. Keith Kelly, who worked with the PI as an undergraduate and a first year Masters student, is now a PhD student at the University of Texas, Austin. Clarissa is outstanding second year graduate student.

In addition, Qing Chu received Honorable Mention for her paper *Wavefront Reconstruction in Adaptive Optics Imaging* at the Copper Mountain Conference on Iterative Methods, March 25-29, 2012. Qing also gave an oral presentation at the conference.

Keith Kelly presented a poster at the 2013 AMOS Conference, September 10-13, 2013.

Clarissa Garvey and Sebastian Berisha participated in the Trilinos User Group Meeting at Sandia National Laboratory, Albuquerque, NM, November 4-5, 2014.

Publications.
The following papers were written in the first two years of this grant:

- A. Cornelio, E. Loli-Piccolomini, and J. G. Nagy. *Constrained Variable Projection Method for Blind Deconvolution*, Journal of Physics: Conference Series, volume 386, issue 1, pages 012005, 2012.

- S. Berisha and J. G. Nagy. *Iterative Methods for Image Restoration*, *Academic Press Library in Signal Processing: Image Video Processing and Analysis, Hardware, Audio, Acoustic and Speech Processing*, Academic Press, editor S. Theodoridis, September 2013.

- Q. Chu, S. M. Jefferies, and J. G. Nagy. *Iterative Wavefront Reconstruction for Astronomical Imaging*, SIAM J. Sci. Comput., volume 35, issue 5, pages S84-S103, 2013.

- J. M. Bardsley, M. Howard, and J. G. Nagy. *Image Deblurring, Gaussian Markov Random Fields, and Neumann Boundary Conditions*, Elect. Trans. Numer. Anal., volume 40, pages 476–488, 2013.

- S. M. Jefferies, D. A. Hope, M. Hart and J. G. Nagy, *High-resolution imaging through strong atmospheric turbulence.* Proceedings of the SPIE, volume 8890, doi:10.1117/12.2028193, October 25, 2013.

- K. W. Kelly and J. G. Nagy. *Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor*, AMOS Technical Conference, Kihei, HI, 2013.

- A. Cornelio, E. Loli-Piccolomini, and J. G. Nagy. *Constrained Numerical Optimization Methods for Blind Deconvolution*, Numerical Algorithms, volume 65, issue 1, pages 23–42, 2014.

- P. C. Hansen, J. G. Nagy and K. Tigkos. *Rotational Image Deblurring with Sparse Matrices*, BIT Numerical Mathematics, 54, pages 649–671, 2014.

- S. Gazzola and J. G. Nagy. *Generalized Arnoldi-Tikonov Method for Sparse Reconstruction*, SIAM J. Sci. Comput., volume 36, issue 2, pages B225-B247, 2014.

- J. G. Nagy, S. M. Jefferies, M. Hart, and D. A. Hope. *Fast Tomographic Reconstruction of Atmospheric Turbulence from Micro-lens Imagery* Proceedings of the Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 9–12, 2014.

- S. Berisha, J. G. Nagy and R. J. Plemmons. *Estimation of Atmospheric PSF Parameters for Hyperspectral Imaging.* Numer. Lin. Alg. Appl., to appear, 2015.

- S. Berisha, J. G. Nagy and R. J. Plemmons. *Deblurring and Sparse Unmixing of Hyperspectral Images using Multiple Point Spread Functions.* SIAM J. Sci. Comput., to appear, 2015.

Conference, Colloquia, and Seminar Activities.
The following talks/lectures were given by PI Nagy:

- *Separable Nonlinear Inverse Problems and the Local Minimum Trap.* Copper Mountain Conference on Iterative Methods.
  Copper Mountain, CO, March 25–29, 2012. Contributed Talk.

- *Implicit Filtering Methods for Inverse Problems.* SIAM Conference on Applied Linear Algebra. Valencia, Spain, June 16–23, 2012.
  Invited Minisymposium Talk.

- *Large Scale Inverse Problems in Image Reconstruction.* SAMSI Opening Workshop on Massive Datasets Program. Research Triangle Park, Durham, NC, September 9-12, 2012.
  Invited Plenary Talk.

- *Wavefront Reconstruction in Adaptive Optics Imaging.* VA Tech Department of Mathematics Colloquium. Blacksburg, VA, November 30, 2012.
  Invited Talk.

- *Hybrid Krylov Subspace Methods for Inverse Problems.* New Frontiers in Numerical Analysis and Scientific Computing Conference, Kent State University, April 18 21, 2013.
  Invited Talk.

- *Iterative Krylov Subspace Methods for Sparse Reconstruction.* International Workshop on Numerical Linear Algebra with Applications, Hong Kong, November 14–19, 2013.
  Invited Talk.

- *Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor*, Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, Kihei HI, 2013.
  Poster Presentation (given by student co-author K. W. Kelly).

- *Iterative Methods for Image Restoration.* 4th Workshop on Mathematical Analysis on Inverse Problems and Imaging, National Astronomical Observatory of Japan, Tokyo, Japan, January 8, 2014.
  Invited Talk.

- *Wavefront Phase Reconstruction using a Frozen Flow Model.* 4th Workshop on Mathematical Analysis on Inverse Problems and Imaging, National Astronomical Observatory of Japan, Tokyo, Japan, January 8, 2014.
  Invited Talk.

- *Imaging Through Strong Turbulence.* SIAM Conference on Imaging Scinece, Hong Kong, China, May 12–14, 2014.
  Organized Minisymposium jointly with S. M. Jefferies.

- *Computational Methods for Inverse Problems with Applications in Image Processing.* University of Padova, Padova, Italy, February 17–25, 2014.
  Invited Short Course for PhD Students.

- *Structured Computations in Multi-Frame Blind Deconvolution.* Structured Matrices and Tensors: Analysis, Algorithms and Applications, National Taiwan University, Taipei, Taiwan, December 8–11, 2014.
  Invited Talk.

- *Tomographic Reconstruction of Atmospheric Turbulence from Microlens Imagery.* Optical Society of America topical meeting on Signal Recovery and Synthesis, Seattle, WA, July 13–17, 2014.
  Invited Talk.

- *Tomographic Reconstruction of Atmospheric Turbulence from Microlens Imagery.* SIAM Conference on Imaging Science, Hong Kong, May 12–14, 2014.
  Invited Talk.

- *Fast Tomographic Reconstruction of Atmospheric Turbulence from Micro-lens Imagery* Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference, September 9–12, 2014.
  Poster Presentation.

- *Numerical Linear Algebra and Blind Deconvolution. Householder Symposium XVIV*, Spa, Belgium, June 9–13, 2014.
  Poster Presentation.

- *Hybrid Constrained Iterative Methods for Inverse Problems.* SIAM-SEAS Conference, University of Alabama at Birmingham, March 20–22, 2015.
  Invited Plenary Talk.

Future research activities resulting from this project. This project has produced several important research publications, and has initiated avenues of further research. In particular, because of this project, we have been inspired to continue work in the following areas:

- We have an ongoing MATLAB software project, called *RestoreTools*, that uses an object oriented approach to implement iterative image deblurring methods. Graduate student Sebastian Berisha has recently worked on updating the package, and has translated some of these codes into C++/MPI implementations for high performance computers. Two other students, Clarissa Garvey and James Herring, are being trained to make further contributions to this aspect of our work.

- The work we have done on using implicit filtering to avoid the local minimum trap in blind deconvolution problems has only scratched the surface of what may be possible. These methods are expensive to implement for complicated blurs, especially for cases where the blur is spatially variant. It is therefore important to focus on spatially variant blind deconvolution problems.

- An area of great interest and activity in the research community is sparse reconstructions. The algorithms for sparse reconstructions are expensive for large scale problems, such as those that arise in multi-frame blind deconvolution. The idea of using sparsity constraints, though, can be helpful in reducing some of the problems associated with local minima, and thus we have been putting a substantial amount of effort into this problem. We have already developed two different approaches for this problem: the first one is based on the idea of the Iteratively Reweighted Least Squares method and can be efficiently implemented in the context of Flexible Krylov Subspaces; the second one is based on restarting the iterative Arnoldi algorithm. A paper on this work has already been published, and we intend to continue working in this important area.

- Related to the previous item is iteratively reweighted least squares methods that account for outliers in data. Our interest in this area is motivated in part by some recent work by Dr. Brandoch Calef (Boeing) on iteratively reweighted MFBD methods. Calef's work shows great promise, and we are interested in developing this further, especially focusing on the efficient computational aspects.

1.

1. Report Type

Final Report

Primary Contact E-mail
Contact email if there is a problem with the report.

nagy@mathcs.emory.edu

Primary Contact Phone Number
Contact phone number if there is a problem with the report

404-727-5601

Organization / Institution name

Emory University

Grant/Contract Title
The full title of the funded effort.

Toward Overcoming the Local Minimum Trap in MFBD

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0084

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

James G. Nagy

Program Manager
The AFOSR Program Manager currently assigned to the award

Julie Moses

Reporting Period Start Date

03/15/2012

Reporting Period End Date

03/14/2015

Abstract

Multi-frame blind deconvolution (MFBD) requires solving an optimization problem with an objective function that may have many local minima. Standard numerical optimization methods may become trapped in one of these local minimum points, resulting in poor image reconstructions. The aim of this proposed research is to develop new computational approaches that help to overcome the local minimum trap for iterative MFBD algorithms. Success in this research requires new approaches in several, interrelated areas, including: obtaining a good initial guess, improved regularization methods and approaches for choosing regularization parameters, mathematical analyses and efficient computational methods to reduce the parameter space, and development of efficient implicit filtering algorithms for large scale optimization problems.

In the three years of this grant, we have developed software, investigated the use of implicit filtering methods to avoid local minima, considered Gaussian Markov random fields to improve regularization, and we have developed methods for sparsity constraints that can be used for large scale MFBD problems. The work done on this, and a previous AFOSR grant, initiated a very productive collaboration with Dr. Stuart Jefferies, IFA, University of Hawaii, Dr. Douglas Hope, U.S. Air Force Academy, and Dr. Michael Hart, Physics and Astronomy, University of Arizona.

Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

SF298 Form

Please attach your SF298 form. A blank SF298 can be found here. Please do not password protect or secure the PDF The maximum file size for an SF298 is 50MB.

AFD-070820-035.pdf

Upload the Report Document. File must be a PDF. Please do not password protect or secure the PDF . The maximum file size for the Report Document is 50MB.

Report_March_2015.pdf

Upload a Report Document, if any. The maximum file size for the Report Document is 50MB.

Archival Publications (published) during reporting period:

A. Cornelio, E. Loli Piccolomini, and J. G. Nagy.
Constrained Variable Projection Method for Blind Deconvolution,
Journal of Physics: Conference Series, volume 386, issue 1, pages 012005, 2012.

S. Berisha and J. G. Nagy.
Iterative Methods for Image Restoration,
book chapter in Academic Press Library in Signal Processing: Image Video Processing and Analysis, Hardware, Audio, Acoustic and Speech Processing,
Academic Press, editor S.~Theodoridis, September 2013.

Q. Chu, S. M. Jefferies, and J. G. Nagy.
Iterative Wavefront Reconstruction for Astronomical Imaging,
SIAM J. Sci. Comput., volume 35, issue 5, pages S84-S103, 2013.

J. M. Bardsley, M. Howard, and J. G. Nagy.
Image Deblurring, Gaussian Markov Random Fields, and Neumann Boundary Conditions,
Elect. Trans. Numer. Anal., volume 40, pages 476--488, 2013.

S. M. Jefferies, D. A. Hope, M. Hart and J. G. Nagy,
High-resolution imaging through strong atmospheric turbulence.
Proceedings of the SPIE, volume 8890, doi:10.1117/12.2028193,
October 25, 2013.

K. W. Kelly and J. G. Nagy.
Parallel Implementation of a Frozen Flow Based Wave-Front Reconstructor,
AMOS Technical Conference, Kihei, HI, 2013.

A. Cornelio, E. Loli Piccolomini, and J. G. Nagy.
Constrained Numerical Optimization Methods for Blind Deconvolution,
Numerical Algorithms, volume 65, issue 1, pages 23--42, 2014.

P. C. Hansen, J. G. Nagy and K. Tigkos.
Rotational Image Deblurring with Sparse Matrices,
BIT Numerical Mathematics, 54, pages 649--671, 2014.

S. Gazzola and J. G. Nagy.
Generalized Arnoldi-Tikonov Method for Sparse Reconstruction,

SIAM J. Sci. Comput., volume 36, issue 2, pages B225-B247, 2014.

J. G. Nagy, S. M. Jefferies, M. Hart, and D. A. Hope.
Fast Tomographic Reconstruction of Atmospheric Turbulence from Micro-lens Imagery,
Proceedings of the Advanced Maui Optical and Space Surveillance Technologies (AMOS) Conference,
September 9--12, 2014.

S. Berisha, J. G. Nagy and R. J. Plemmons.
Estimation of Atmospheric PSF Parameters for Hyperspectral Imaging,
Numer. Lin. Alg. Appl., to appear, 2015.

S. Berisha, J. G. Nagy and R. J. Plemmons.
Deblurring and Sparse Unmixing of Hyperspectral Images using Multiple Point Spread Functions,
SIAM J. Sci. Comput., to appear, 2015.

Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

E-mail user

Jul 13, 2015 12:01:30 Success: Email Sent to: nagy@mathcs.emory.edu